

AVULSION OF THE BRACHIAL PLEXUS, WITH A REPORT OF THREE CASES.

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AVULSION of the brachial plexus without the loss of the arm seems to be a very rare accident. Besides the cases recorded by Bowlby, I have been able to find but one other, that of Milliard in the *International Clinics*, Vol. ii, Series 3. Correspondence with many surgeons of the largest experience in this country emphasizes the rarity of the accident. Dr. Nicolas Senn writes, "I have seen but one case of avulsion of the plexus caused by a tree falling on the shoulder. I considered the case hopeless." So far as I have been able to discover, but two other surgeons have seen cases. One of these cases, operated upon by Hartley, of New York, subsequently came under my care and is included in the cases personally seen by me. The other was that of Dr. P. R. Bolton, of New York, of which an account is published in *ANNALS OF SURGERY* for May, 1902. Richardson, of Boston, Park, of Buffalo, White and Da Costa, of Philadelphia, McBurney, Bull, Weir, Bryant, Abbe, Gerster, Wyeth, Dabarn, Lange, Stimson, and Halsted of Johns Hopkins, all write that they have never seen a case, nor have my own colleagues in Brooklyn. In Bowlby's work on injuries of the nerves there are nineteen instances of avulsion of the plexus, but one of these occurring in an infant was certainly not an avulsion, as a certain amount of motion and sensation was subsequently regained without operation. This case should

rather be placed in another class in which belong instances of paralysis from stretching of the plexus. Including the case of Milliard, referred to before, the case of Senn, of Hartley, and Bolton, the writer has been able to collect twenty-four undoubted instances of avulsion of the brachial plexus not accompanied by loss of the limb. Seven of these occurred as the result of forcible reduction of dislocations, four resulted from heavy falls on the shoulder, two were occasioned by blows on the shoulder received in railroad accidents, and five were caused by falling objects striking the shoulder. Three were caused by traction of the extended arm. The cause of the remaining cases is unknown. Very few of these injuries received operative treatment. In the cases reported by Bowlby, but two were submitted to operation. Banks's patient was a sailor, who fell on his shoulder down the hatchway about a couple of months before coming under notice. The pulse was absent in the radial, ulnar, brachial, and axillary arteries. The deltoid muscle alone reacted to faradism and the great pectoral very slightly. An exploratory operation revealed that the plexus had been torn away bodily from the spinal column and had been dragged below the clavicle, with the exception of one small cord which appeared to supply the deltoid and pectoralis major. No mention is made of any attempt at suture. The axillary artery had been injured and was found obliterated. The other case upon which operation was done was that of a man who had been hit on the shoulder by a buffer of an engine, which fractured the clavicle and the upper extremity of the humerus. The patient said that all feeling and motion had gone from the arm when he recovered consciousness. Six months later, under the impression that the axillary nerves might have been torn, they were freely exposed in the axilla, but were found intact. This seems to have been an entirely futile procedure, for, unless the subclavian triangle was opened and the origin of the plexus sought in the neck, it would have been utterly impossible to state that the trunks had not been avulsed from the several nerves composing them, and, as the operation was done so long after the accident, trac-

tion of the nerves in the axilla would prove nothing, for the torn ends would have very speedily contracted adhesions. This was shown by one autopsy. Therefore, no conclusion could reasonably be drawn from the fact that the cords resisted traction where exposed in the axilla. I have therefore retained this case as one of avulsion of the plexus. Senn states that he regarded his case as hopeless. Hartley submitted his case to operation. Of the three cases that came under the care of the writer, one of them was seen three years after the accident and was considered hopeless. The second case was that of Hartley seen one year after operation. The third case coming under observation just after the accident was operated upon by the writer on the third day. The history of the three cases is as follows:

CASE I.—Three years after the accident, there came into the Long Island College Hospital a man with complete paralysis of both motion and sensation in the right upper extremity. He stated that, while at a fire in a country town in Connecticut, a falling ladder struck him on the shoulder and felled him to the ground. On regaining consciousness he found that sensation and motion had both disappeared from his arm. There was also a fracture of the clavicle in its middle third. On examination, there appeared to be but a moderate amount of displacement of the fragments, with good union and no excessive callus. Sensation was entirely gone except over the area of the intercostohumeral nerves. All the muscles were much wasted. Their reactions were not tested, nor were the pupils compared. No operation was proposed, as the length of time which had elapsed since the receipt of the injury seemed to render inevitable the degeneration of the nerve tracts in the spinal cord, and the man passed from observation.

CASE II.—Dr. Hartley's case seen by me one year after operation. In December of 1901 a physician of this city brought to my clinic at the Long Island College Hospital a Swede with a total paralysis of motion in the right upper extremity and a paralysis of sensation, also complete except the area supplied by the intercostohumeral nerves. There was an operation scar over the site of the brachial plexus, and, as the patient said that he had been operated upon by Dr. Hartley, of the New York Hospital, I com-

municated with him, and he kindly furnished me with the following particulars. The patient had fallen through a hatchway for three stories, and part way down his arm had caught in a rope, which, however, held him but a moment as he fell. On admission to the hospital, it was supposed that he had received a fracture of the skull as well as the injury to the arm. When he had recovered sufficiently to admit of operation, Dr. Hartley cut down on the plexus for the purpose of suturing it. The clavicle was resected for the better exposure of the plexus, which was found much torn and with frayed-out ends, buried in much cicatricial tissue. The operator was unable to bring the ends in apposition, and was obliged to use catgut sutures *à distance*. He wrote me that the operation was most unsatisfactory. I regret that I made no precise record of the paralyzed areas at the time I first saw this patient. My recollection, however, is that there was a total motor and sensory paralysis of the entire arm, with the exception of the intercostohumeral area. At present his condition seems not entirely hopeless. He has regained the use of the internal and external rotators of the arm, and has recovered sensation over the upper arm in all areas save that supplied by the internal cutaneous nerve. There is also a triangular area on the posterior surface of the forearm just below the olecranon which has some modified sensation. He complains of feeling some pain in the fingers, but, with the exception of the small area mentioned, there is a total paralysis of the forearm with much wasting of muscles. Those of the upper arm do not seem to be wasted in proportion. He has the contracted pupil and diminished palpebral fissure which indicate sympathetic involvement, but says he is not conscious of sweating less on the affected side than on the other. There is no œdema of the arm and there is a normal sense of warmth to the touch.

CASE III.—The patient, a colored man, sailor by occupation, was brought into the Long Island College Hospital one Sunday with a complete paralysis involving the left upper extremity, with the exception of the sensory area of the intercostohumeral and the circumflex nerves. There was also a fracture of the ulna. The injury had been received in the following manner. While at work about a steam-winch on the vessel, the patient had attempted to throw the rope into place while the steam was on, and his forearm, becoming entangled in the rope, was dragged under the winch. There was not much pain at the time. After

his arrival at the hospital he felt severe pain, which was referred to the arm, which he said had the sensation always of extreme extension. A careful examination showed that it was probable that the plexus had been avulsed; and from the fact that there was considerable swelling in the inner region of the subclavian triangle, and that the left pupil was contracted, it seemed most probable that the nerves had given way close to the intervertebral foramina. From the fact that the convexity of the shoulder down to the insertion of the deltoid preserved sensation, it also seemed likely that some fibres, at any rate of the posterior cord, still maintained their integrity. This, however, proved to be erroneous. The effusion at the base of the neck negatived the supposition that the nerves had been simply stretched, an injury which has actually happened several times, as evidenced by the subsequent return of motion and sensation at varying periods without operation.

The writer determined first to cut down on the subclavian triangle for the purpose of exploration, further procedure to be governed by the conditions disclosed. The exploratory incision was begun posterior to the sternomastoid, on a level with the lower border of the thyroid cartilage, and was carried down to the clavicle and thence along the bone to the acromioclavicular joint. A triangular flap turned back gave ample exposure of the origin of the plexus. On opening the deep fascia some recent blood-clot was exposed. Neither the cords nor trunks of the plexus, however, could be found. Short stumps just protruding from the cellular tissue between the anterior and middle scalenes were all that could be seen of the nervous structures. They were much frayed and ragged, and perhaps half an inch long. It was evident that the plexus had given way just at the point where the four cervical nerves and the last dorsal unite to make up the three trunks, the nerves giving way from above downward as the strain came upon them successively. The lost trunks could not be seen in the wound. A third incision was therefore made, commencing just a little to the inner side of the acromial process, and this was carried downward and inward, so that it lay parallel to the incision in the neck. The clavicle was now sawn asunder and the two pectorals divided. The ends of the clavicle being retracted, a full view of the whole tract occupied by the plexus was plainly in sight. The nerves were traced from below upward, and the torn ends of the trunks found well underneath the clavicle. There

was no difficulty in bringing the torn and ragged ends of the three trunks up to the stumps of the nerves in the neck, as in Hartley's case. Indeed, it was evident that before the nerves had given way they had stretched greatly, so that it was possible to cut off the ragged portions of the trunks; but when it came to restoring the original anatomical relations, that was quite another matter, for it was not possible to determine which part of each trunk belonged to the several nerves of origin. It was possible, however, to identify the trunks, and these were sutured with catgut in their natural order. The ends of the sawn clavicle were then united with chromicized catgut and the large wound closed, the arm being secured to the chest in a Sayre dressing of adhesive plaster. No febrile reaction followed, and the stitches were removed at the end of a week. One month after operation the condition of the patient was as follows. With regard to the electrical reactions which were kindly tested for me at the Polhemus Clinic by Dr. Onuf, it was found that the reaction to the faradic current was entirely lost in all the muscles supplied by the brachial plexus, those of the scapula suffering as much as the intrinsic muscles of the arm and forearm. The trapezius reacted very feebly. The sternomastoid somewhat more strongly, but still deficient. The reaction of degeneration was present in the anterior fibres of the deltoid in the biceps and triceps, but was sluggish and greatly diminished. There was no response whatever in the extensor and flexor groups of the wrist and fingers. Sensation has never been absent over the sensory area usually supplied by the circumflex nerve. The area of the nerve of Wrisberg and of the internal cutaneous branch of the musculospiral has regained sensation, which was lost at the time of operation. The skin of the arm and forearm was in a condition resembling senile atrophy, and was much darker than the other side. On the sound side it was noted particularly that the electrical reactions were weaker than normal, and there was a slightly increased tendon reflex at the knee, that on the injured side, however, being normal.

The following symptoms denoting injury to the sympathetic were present. The left pupil was contracted more than the right. The palpebral fissure was much diminished. The eyeball appeared to be smaller than its fellow, less prominent, and of less tension. The vision was less perfect. The left ear was somewhat colder

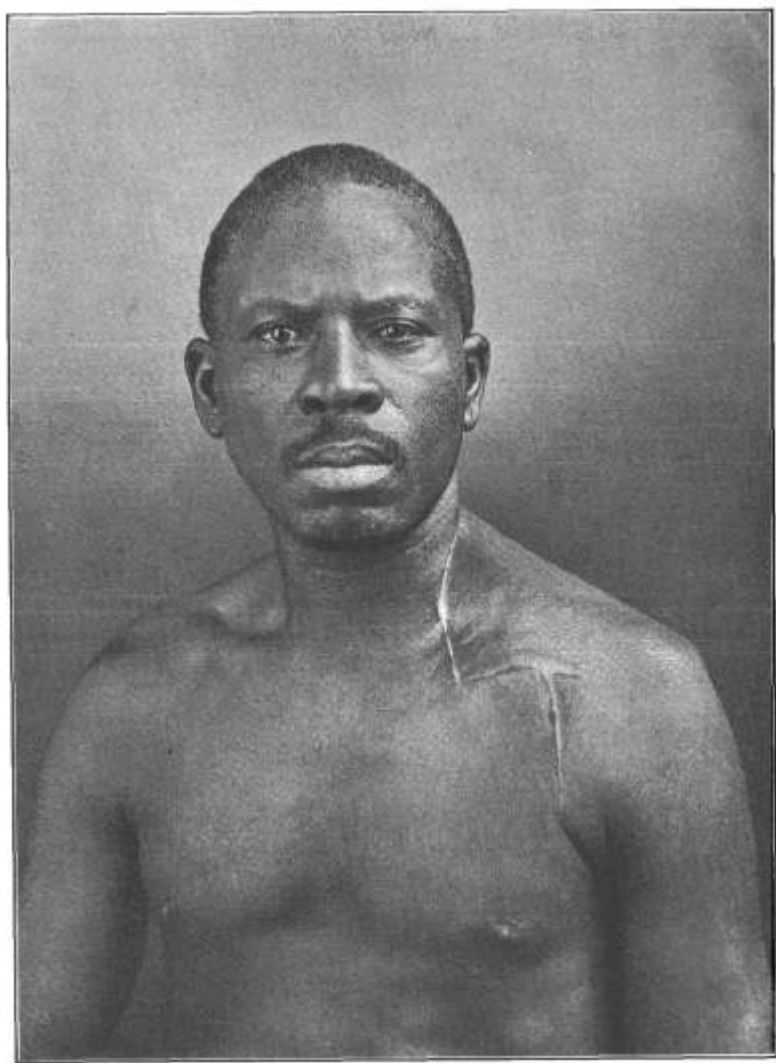


FIG. 1.—Showing diminished palpebral fissure on injured side, with slight hemiatrophy of face.

than the right, and there was a condition of the skin on the affected side, particularly of the arm and forearm, which resembled senile atrophy. There was some hemiatrophy of the face; but there did not appear to be any special dryness either of the conjunctiva, nostril, or mouth on the injured side. Four days later, some cedema had made its appearance in the arm and forearm, and there was a distinct gain in the sensation in the areas before mentioned.

There are a number of interesting problems which present themselves in the review of this symptom complex. First, as to the preservation of sensation over the area usually supplied by the circumflex. This may be due to one of two facts. Either the filaments of the supra-acromial branch of the cervical plexus came lower down than usual in this man, or the preservation of sensation is due to collaterals *already* existing or developing between the supra-acromial and circumflex nerves, through which paths sensory impulses now travel from the area of the circumflex nerve. In support of such a possibility. Bowlby states that if the parts supplied by a divided nerve be tested with care, it will very frequently be found that they are not completely anæsthetic. This sensation he calls supplementary sensation, and proceeds to give a number of instances. To quote two will suffice. "A young woman sustained a cut across the wrist which divided the median nerve. Richet wished to demonstrate the result of section of a nerve. To his astonishment, sensation was preserved when he touched the thumb, middle, and ring fingers."

Baudens records a more astonishing case. "A Zouave received a sabre-cut in the axilla which divided many muscles, —the axillary artery and the median, ulnar, internal cutaneous, and musculocutaneous nerves. The limb remained warm, and after twenty-four hours the least pressure on the hands and fingers was painful. During the following days sensation became blunted, but so long as the patient lived, no cutaneous anæsthesia could be established in any part of the upper extremity. While it is true that there are areas of overlapping, in nerve-supply this fact hardly explains such cases. I have a case of my own at present where there is diminished sensation

over the sensory area of the musculospiral nerve, but, with the exception of slight power of extension of the fingers, a complete motor paralysis of the extensors and supinators as a result of injury. In the case under discussion, sensation has returned to the area of the nerve of Wrisberg and the territory of the internal cutaneous branch of the musculospiral. Is this due to a reunion of the conducting fibres in the neck or the establishment of a collateral sensibility? It is quite certain that the territories in question were completely anæsthetic at the time of operation. Sensation, moreover, since it first reappeared, has improved. Is this due to the establishment of collateral paths by way of the intercostohumeral nerves which supply the territory next adjacent, or to reunion of the torn nerves? So sharply is the area of the nerve of Wrisberg outlined by returning sensation, that it would make an excellent example to demonstrate the distribution of the nerve before a class, and it seems like assuming a great deal to say that the returning sensation is due to collateral paths. Nevertheless, it ought to be remembered that the nerve of Wrisberg receives filaments from both the second and third intercostals, and that it is not impossible that sensory impulses now take this path. The return of sensation to the internal cutaneous branch of the musculospiral without any evidence of repair in the motor paths or in the radial distribution is more difficult. It is not strange that in the phenomena of repair, sensation should return before motion, for the phenomena of sensation are dependent on the regeneration of the nerve alone, while the restoration of motion must depend somewhat on the regeneration of the wasted muscle. If reunion has taken place so that the sensory paths of the internal cutaneous branch are travelling by their accustomed route, why does not the radial transmit sensory impulses? Do sensory waves travel through the adjacent nerve of Wrisberg and the intercostohumeral nerve by collateral connections of the adjacent systems? This seems a possibility, at least when we remember the terrific stretching that the plexus received before giving way, and bear in mind, also, the long period of time that

elapses before restoration of function after stretching of nerve-trunks in other parts of the body.

Certain peculiarities in the architecture of the brachial plexus have some bearing on this point. If the three trunks are torn from their constituent nerve-roots, there are still two communications between the spinal cord and the axillary part of the torn plexus, namely, above by the small cord of communication between the fourth and fifth cervical nerves and below by the loops of communication between the nerve of Wrisberg and the intercostohumerals with the first, second, and third intercostal nerves. The upper branch of communication is almost certain to be torn by the plexus as it disappears beneath the clavicle. The lower branch, however, is never torn, as from its position it cannot be injured, as evidenced from the fact that all the recorded cases have retained sensation in the area supplied by the intercostohumeral nerves. Now, in both Hartley's case and my own sensation has returned in those parts of the cutaneous distribution of the musculospiral nerve which are adjacent to the territory of the nerve of Wrisberg and in the area of Wrisberg itself, that being directly adjacent to the intercostohumeral area. The area of the internal cutaneous, however, which lies between the intercostohumeral area and the internal cutaneous branch of the musculospiral is still anæsthetic. There are no loops of communication, be it observed, between the nerve of Wrisberg and the internal cutaneous, although both are branches of the inner cord, whereas the loops between the intercostohumeral and the nerve of Wrisberg have already been pointed out. A somewhat unexpected discovery was that of the partial paralysis of the sternomastoid and the more complete paralysis of the trapezius, though the latter muscle still retained some power. When we remember the origin of the spinal accessory, together with the fact that all of these cases bear evidence of injury to the sympathetic, the two symptoms seem at first to belong together. The spinal portion of the accessory arises by filaments which extend from the first to the sixth cervical nerve and pass up between the ligamentum

denticulatum and the posterior root of the spinal nerves. The sympathetic nerve receives branches of communication from the anterior roots of the cervical spinal nerves. When the plexus was put upon the stretch and before it gave way, the rami communicantes of the sympathetic corresponding to the five spinal nerves which make up the plexus must have been torn or greatly stretched. At the same time the traction exerted on the cord may have damaged the filaments which make up the spinal portion of the eleventh cranial nerve, or possibly that portion of the lateral column from which the filaments emerge may have been bruised. It seems impossible, however, that the first supposition can have been correct, from the protected situation of the filaments of origin within the spinal canal; and if the lateral column was sufficiently bruised to interfere with the transmission of impulses through fibres arising at the point of bruising, we should expect symptoms of lateral column mischief at other points. There are none, however. The most reasonable hypothesis is that the traction on the shoulder also stretched the nerve as it enters the trapezius muscle, so that it received its greatest injury just before entering the muscle. If this were so, then the trapezius ought to be more paralyzed than the sternomastoid, which is the case. On the other hand, if the injury had taken place in the filaments of origin, both muscles would have suffered equally, which is not the case.

The symptoms of injury to the sympathetic deserve some consideration. The contraction of the pupil of the affected side is evidently due to the fact that the sympathetic nerve has lost the ciliospinal fibres which join it from the first and second dorsal nerves. The pupillary phenomenon was first demonstrated by Pourfour du Petit in 1727. G. Fischer excised the cervical sympathetic in two decapitated men and produced opening of the palpebral fissure, dilatation of the pupil, protrusion of the cornea, and lachrymation. Exactly the reverse of these symptoms is present in the case under consideration. The narrowing of the palpebral fissure is due to a paralysis of those bands of unstriated muscle in the upper lid known

as Müller's muscle. The sinking in of the eyeball may be due to the shrinking of the cushion of fat in the orbit, and this in turn to nutritive changes due to a paralysis of the vasodilators in the blood-vessels. Ogle, quoted by Bowlby, ascribes this symptom to the paralysis of a funnel-shaped layer of involuntary muscle which has been shown by Prevost to have the power of causing protrusion of the eyeball. (Morris, the orbital muscle of Müller.) There is probably a change in the actual diameter of the eye as well, as there is certainly a change in the intraocular tension. Both Claude Bernard and Brown-Sequard found that section of the sympathetic causes flattening of the cornea. The hemiatrophy of the face, the coldness of the ear, the anidrosis of the face, neck, and arm of the affected side seem to support the theory of the influence of the sympathetic over the function of the sudoriferous glands. A hemiatrophy which does not depend on the wasting of paralyzed muscle must depend on other nutritive changes producing shrinkage of tissues, and this could be brought about by a paralysis of the vasodilators which would leave the constrictors unopposed. A similar explanation may be invoked to account for the anidrosis, for the production of sweat is, if not entirely, nevertheless in part, dependent on an increased blood supply to the glands. Adamkiewicz, Vulpian, and others have striven to show that the secretion of sweat is due to an independent set of fibres, but the matter is still in doubt. Landois and Stirling say that the secretory nerves and those for the blood-vessels seem to lie in the same trunks. Nevertheless, although it is known that all the nerves constituting the brachial plexus were disrupted in this case, still, sweating does occur, although to a diminished degree, on the injured side. The curious wrinkling of the skin that was observed to be present for a time has been noted in other instances of this injury, and may be due to a paralysis of the unstripped muscle fibres of the skin. (Payne quoted by Bowlby.) The œdema of the arm which has been occasionally observed did not at first exist in my case until some days after the Sayre dressing had been removed, and the forearm and elbow allowed to rest

in an ordinary sling. The œdema was, when it appeared, greatest in the forearm, and ceased rather abruptly at the level of the insertion of the deltoid muscle. After a week or two it disappeared. Whether this symptom was due to the injury of the sympathetic or not is doubtful. Angioneurotic œdema, say Onuf and Collins ("Experimental Researches on the Sympathetic") furnishes the most exquisite type of a serous exudate secondary to vasomotor influence. It is possible that the œdema was of this type. Nevertheless, if the exudate was due to a relaxation of vascular tension, we are left in the dilemma of calling on a dilator paralysis to account for one set of symptoms and a constrictor paralysis to account for another set. It seems, if both are present, that the vessels ought to be in a condition of equilibrium so far as their caliber is concerned, but to have lost all power of adjusting themselves to circumstances. Mention has been made of the fact that the muscular reactions on the uninjured side were slightly subnormal, and that the knee-jerk was slightly increased, while normal on the injured side. This impairment of muscular reaction on the uninjured side may have been due to traction on the cord itself at the time of the accident, and a consequent stretching of the plexus of the other side. This is not a purely theoretical conjecture, as the experiments of Bowlby and others show. In this connection, Bowlby says, "If the brachial plexus be exposed in the neck, the cord can certainly be drawn upon if sufficient force be applied." Finally, what is the prognosis of injuries of this description, and what ought to be their treatment? In discussing the first question, it is to be noted that the separation of nerve-trunks by avulsion offers an essentially different problem to the simple division of nerves by cutting instruments. In the latter cases, the nerve-trunk has received no injury save the division of its fibres at the point of incision, and repair may be expected when the ends are sutured promptly. Even after months of delay, if the nerve ends are found and sutured there are many cases on record which show that the return of function may confidently be expected. It is quite different, however, with an avulsed

nerve. Here the nervous structures for some distance have been severely stretched; so that to the accident of separation we must add the effects of the severest possible stretching. Briefly, these consist in segmentation of the myelin, breaking of the sheath of Schwann, loosening of the sheath from its attachments to the nerve, with constriction of the tubules, all these phenomena occurring not simply at the point of rupture, but extending for some distance therefrom. (Marcus and Wiet, cited by Bowlby.) In considering the progress of repair, it is then evident that the injury to the nerves is far more wide-spread in cases of avulsion than in the more common cases of simple division. We must expect, therefore, that the period of repair will be longer and the return of function much later. Dr. Hartley's case shows the wisdom of early operation. There, owing to circumstances, it was not possible to interfere at once, and when the operation was undertaken, the peripheral ends were buried in a mass of cicatricial tissue, and so contracted that it was impossible to bring them up to the central ends, therefore the *suture à distance* was resorted to, which does not offer so good a prospect as absolute approximation. To illustrate the disadvantages of this method, attention is called to Fig. 2, which is a section excised from the median nerve under the following circumstances. A United States soldier, while on the march to Peking, received a Mauser bullet wound of the forearm, which healed without incident, but left a paralysis of the parts supplied by the median nerve. A few months afterwards, as he was suffering from much pain at the seat of the injury, the nerve was exposed, and a neuroma was excised together with about three inches of the nerve. It was not possible, after the excision, to bring the ends of the nerve together, and catgut *sutures à distance* were used as in Hartley's case. One year after this he came under the care of the writer, complaining of atrocious pain at the site of the first injury, but without any return of either sensation or motion below this point. The nerve was again exposed, and a fusiform mass about an inch and a half in length was excised. On flexing the wrist, apposition of the

ends was easily attained, and the pain of which the patient had complained was relieved. Sections were made of the excised portion of the nerve, and the figure shows what had taken place along the *suture à distance*. It is evident that most of the new tissue is fibrous, and that there is no continuity whatever of the axis cylinders. The pain may be accounted for by the imprisonment of nervous tissue in what



FIG. 2.—Section of pseudoneuroma of median nerve after suture *à distance*.
A, nerve-fibril; B, fibrous tissue.

is nothing more than a cicatrix, and while on inspection at the time of operation the nerve seemed continuous, it was really not so, the bridge consisting merely of fibrous tissue. If good results are to be anticipated, it seems important then to interfere as soon as possible after the injury. The longer the interval which elapses, the less the prospect of the restoration of function. There seems to be an advantage in the division of the pectoralis minor and the upper part of the major, as by this manœuvre the three cords may be easily iden-

tified in the upper axilla, and from thence easily traced upward. Without operation, of course no return of function can be expected.

[NOTE.—Since writing the above, in the writer's case sensation has returned to the area of the internal cutaneous nerve, so that the patient now has complete sensation over the entire upper arm. He states that, with the arm bent at a right angle and carried in a sling, he feels as if the arm was "sticking straight out from the elbow," which is, of course, the last sensation that the cortex recorded before it was cut off from communication with the arm.]